Accelerator Test Facility History

The Accelerator Test Facility (ATF) at Brookhaven National Laboratory (BNL) has been in operation since 1992. The ATF is the nation's only experimental facility operated for accelerator scientists as a proposal-driven, program-committee reviewed users facility. This document is a brief history of this unique facility and also provides some information about its capabilities, achievements and budget. More information can be obtained at the ATF web site, http://www.atf.bnl.gov .

The ATF got started as a high-brightness linac R&D by BNL's Claudio Pellegrini and Robert Palmer in about 1986. The facility got its initial funding from the system of Exploratory Research Program (now known as Laboratory Directed Research and Development). In 1986 to 1988 the program's goal was to prototype an electron gun and do modeling of a 50-100 MeV linac, capable of producing a high brightness electron beam, to be used in the future for the production of coherent radiation in the IR to soft X-ray region and laser acceleration of electrons. In 1989 to 1990 the work concentrated on the ATF facility prototypes: linac, rf systems, low energy beam transport, FEL resonator and wiggler R&D, control system and gun testing.

Ilan Ben-Zvi, who arrived at the ATF in 1988, was appointed the director of the facility in 1989, following the departure of Claudio Pellegrini to UCLA. Later in 1989 the first User and Program Committee meeting was held for the first time and six experiments were approved for operation in the facility, which was still under construction. The ATF Program Committee is also serving as a Steering Committee for the BNL Center for Accelerator Physics, (CAP) headed by Bob Palmer.
The membership of the ATF Program Committee comprises of blue-ribbon accelerator scientists from universities and national laboratories. It was first chaired by Andrew Sessler (Lawrence Berkeley National Laboratory), then by Maury Tigner (Cornell University), followed by Robert Siemann (Stanford Linear Accelerator Center) and currently by Chan Joshi (University of California at Los Angeles). The committee members are appointed by the head of CAP.
Thus the direction for the ATF comes from both CAP and the National Synchrotron Light Source (NSLS) department. The ATF staff-members are affiliated with the NSLS, which also provides administrative, ES&H and engineering and technical support for the ATF.

Since any LDRD funding is limited to two or three years at most, the future of the budding facility depended on stable, larger scale support from the DOE. A proposal to "complete and operate the ATF as a User facility dedicated for the Physics of Beams" was submitted to the DOE in March 1990. The emphasis was on the special capability of the ATF to provide a high-brightness electron beam and high-power lasers, synchronized with high precision to the electron beam. That makes it possible to 'wed' lasers to accelerators, opening for the first time systematic research on the interaction of high power electromagnetic radiation with high-phase-space-density electron beams, a subject reach in applications. Some of the intriguing applications are laser acceleration of electrons, Free-Electron Lasers, generation of ultra-short electron bunches (microbunches) and much more.

The proposal was accepted, and since then the ATF has been funded by the DOE, as can be seen from Table 1.

Prior to 1990 there has been some limited DOE support, but the support took over from the LDRD only in FY'91. In addition, the ATF continued to enjoy BNL Directorate support for general plant projects and LDRD dedicated for special experiments. Examples of support in general plant projects are the construction of the ATF Experiment Hall, (shown in figure 1), the ATF power-supply and RF control mezzanine and the construction of the photocathode laser clean room complex. LDRD support has been provided, beyond the bootstrapping initial support, to experiments such as the Visible FEL and High-Gain Harmonic-Generation experiments and for the development of higher brightness electron beams. In addition, the ATF benefited greatly from its membership in the NSLS department and received considerable engineering and technical support. A great deal of the know-how that went into the construction of the ATF came from individuals such as Kenneth Batchelor, Joseph Sheehan and Martin Woodle, to name a few. The association with CAP brought other talents into play, in particular one may name Harold Kirk, Richard Fernow and Juan Gallardo of the Physics Department, and Triveni Srinivasan-Rao and (the late) Joachim Fischer from the Instrumentation Division.

Year	Operating	capital
1989	122	119
1990	141	463

1991	909	435
1992	1,195	600
1993	1,249	300
1994	1,138	525
1995	1,223	200
1996	1,225	409
1997	1,266	100
1998	1,460	200
1999	1,545	200
2000	1,585	250
Totals	**13,058**	**3,931**

Table 1. DOE funding of the BNL Accelerator Test Facility (units $1000).

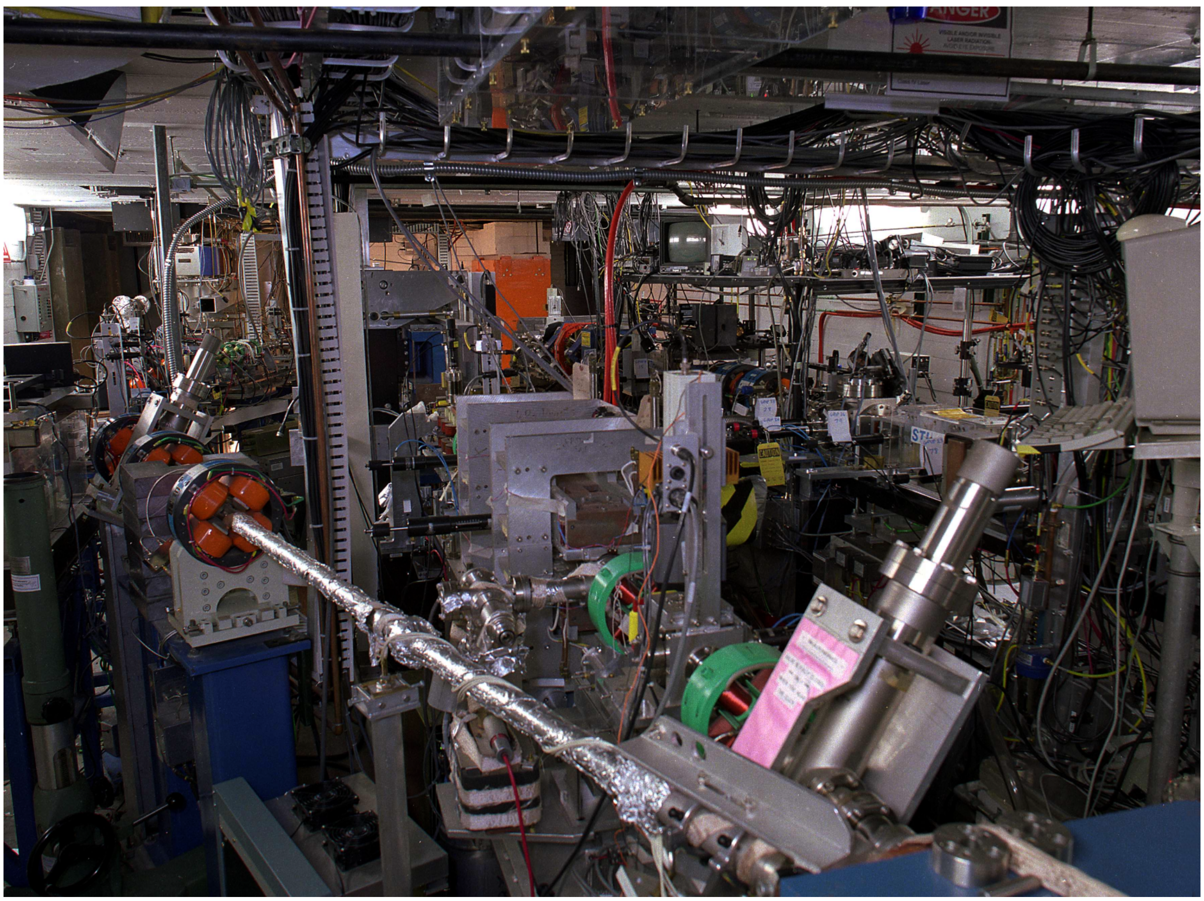

Figure 1. The ATF Experiment Hall.

The first experiment to operate at the ATF in 1992 was the Smith-Purcell radiation experiment, using the 4.5 MeV electron beam from the ATF photoinjector, by a team from Dartmouth, MIT and BNL. The study of photocathodes, developed by Triveni Srinivasan-Rao and Joe Fischer was also proceeding with the gun. Later in the same year, the 45 MeV electron beam was propagated to the newly constructed Experiment Hall and the ATF became operational.

In the first few years of the ATF, the number of experiments grew rapidly. Later on the number reached a steady state, with experiments retiring at about the same rate as experiments were being approved. This can be seen in Figure 2.

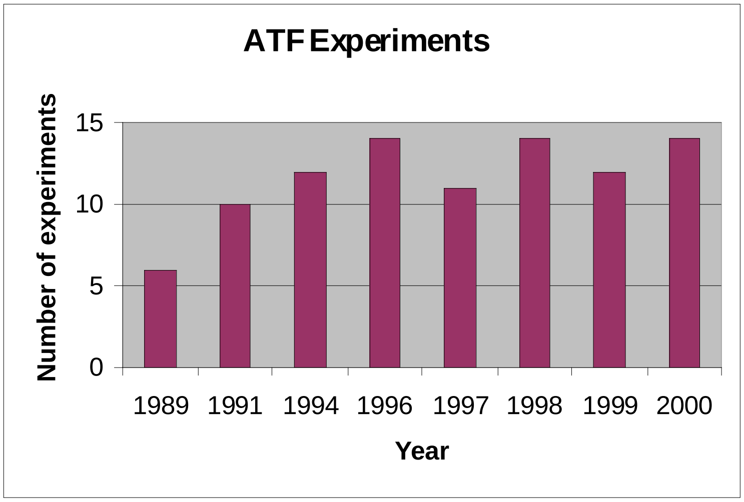

Figure2. The number of ATF experiments as a function of time.

At the same time the complexity, sophistication and cost of the experiments continues to grow. The cost of some of the experiments runs in the millions of dollars, provided at times by multi-institutional collaborations. The growth of the scientific activity let to a lot of published results and invited papers in meetings. The number of publications vs. year can be seen in Figure 3.

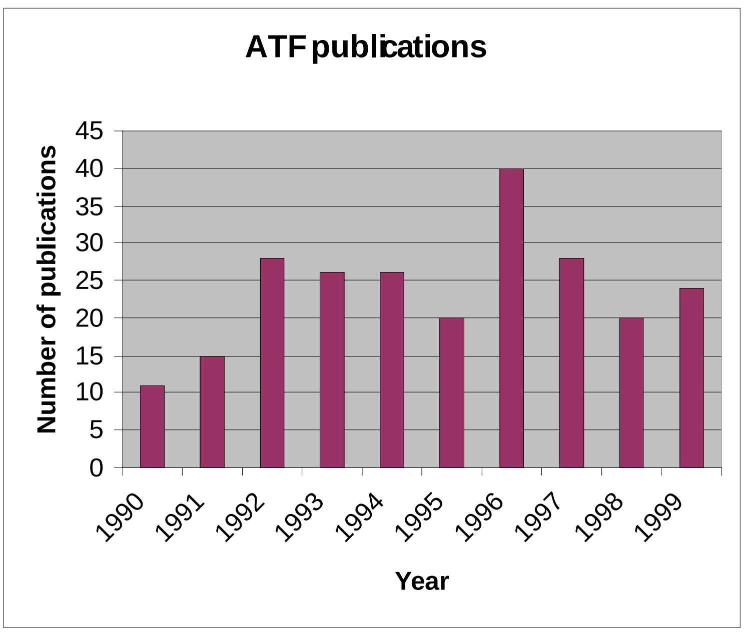

Figure 3. The number of ATF publications as a function of year of publication, from 1990 to 1999.

We at the ATF take pride also in the contribution we provide to the education of graduate students and post docs in accelerator physics. ATF students come from all across the nation, from Ivy League schools to large State Universities and small colleges. The number of students graduating per year and the cumulative number of graduations is shown in Figure 4. The distribution of 17 students (alumni and current students) is shown in Figure 5.

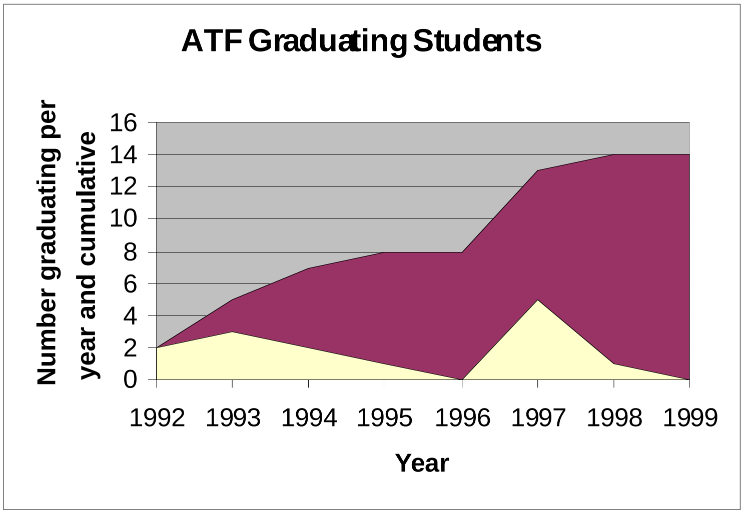

Figure 4. Graduate students by year of graduation (yellow) and cumulative total (red).

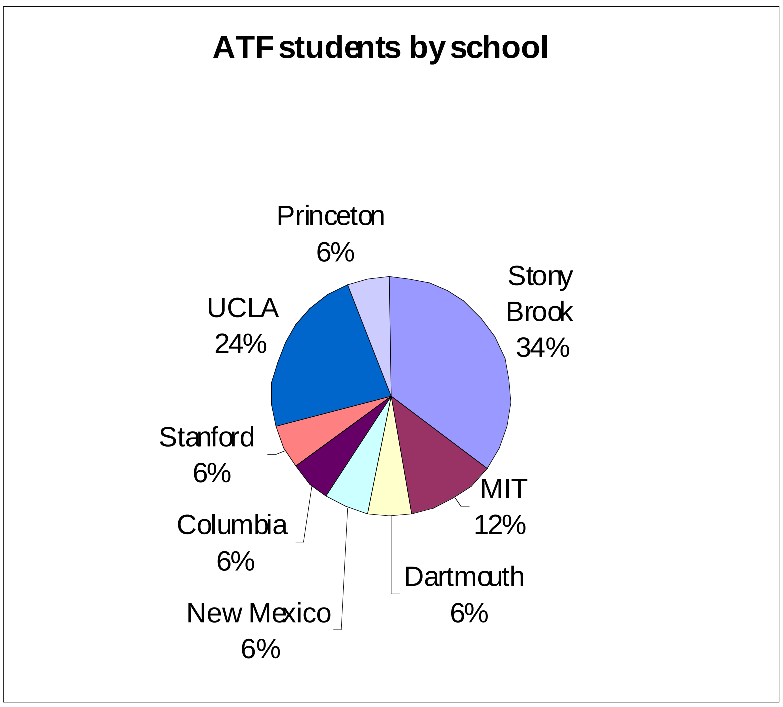

Figure 5. The distribution of 17 ATF graduate students by school.

As a by-product of the R&D to improve the beam brightness, the ATF became a world-leader in the development of laser photocathode RF guns (photoinjectors). The ATF initial gun made its way to France, CERN, Rocketdyne Inc. and UCLA. The second gun, developed as a CRADA with Grumman powered a compact FEL at Princeton and a laser - beam chemical research facility at BNL. The third generation gun made its way to SLAC, UCLA and BNL, and the fourth one is in ANL, BNL and Japan. At the same time the science of metal photocathode was pushed to new heights at BNL with copper, magnesium and niobium cathodes providing high quantum efficiency and long lifetimes. Figure 6 shows a picture of the ATF Gun IV, the latest in the series.

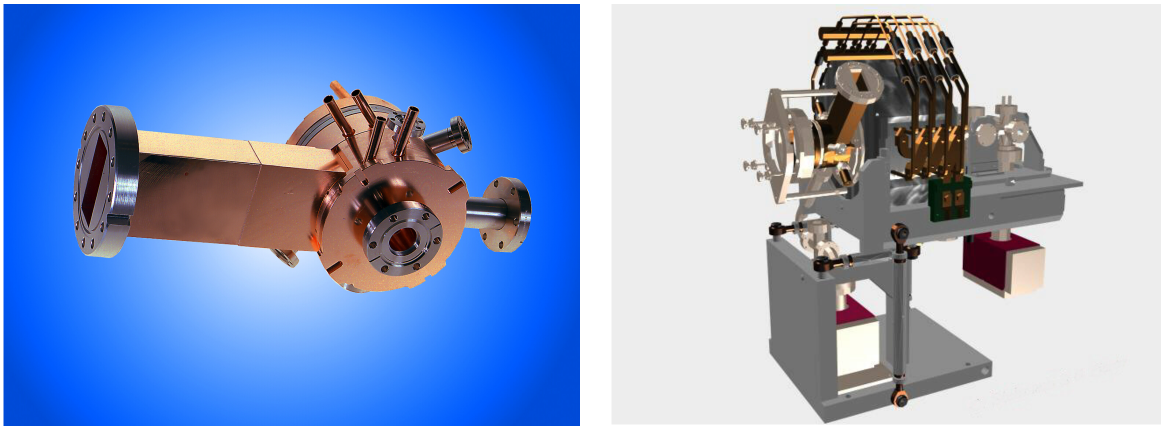

Figure 6. ATF gun IV (left) and a rendition of a complete gun assembly (right).

Another way to look at the history of the ATF is to follow a few landmark experimental results. The first achievement was in the area of laser acceleration of electrons, the demonstration of a 3.5 MeV acceleration of electrons using the Inverse Cerenkov effect. The results of the experiment, led by Wayne Kimura of STI Optronics Inc. of Bellevue, Washington, were published in 1995 [W.D. Kimura, G.H. Kim, R.D. Romea, L.C. Steinhauer, I.V. Pogorelsky, K.P. Kusche, R.C. Fernow, X.J. Wang and Y. Liu, "Laser Acceleration of Relativistic Electrons Using the Inverse Cerenkov Effect", Phys. Rev. Let. 74, 546 (1995)]. At about the same time, an experiment probing the Smith-Purcell mechanism of radiation generation from relativistic electrons got interesting results showing forward directed radiation from a grating [K.J. Woods, J.E. Walsh, R.E. Stoner, H.G. Kirk and R.C. Fernow, "Forward Directed Smith-Purcell Radiation from Relativistic Electrons", Phys. Rev. Let. 74, 3808 (1995)].

The development of sophisticated electron beam diagnostics turned out to be a very prolific area of research at the ATF. The first major result has been the measurement of emittance of individual picosecond-long slices of an electron bunch, demonstrating the mechanism of emittance correction at work. [X. Qiu, K. Batchelor, I. Ben-Zvi and X.J. Wang, "Demonstration of Emittance Compensation through the Measurement of the Slice Emittance of a 10-ps Electron Bunch, Phys. Rev. Let. 76, 3723 (1996)].

Another landmark result in laser acceleration was the Inverse Free-Electron Laser experiment, led by Arie van Steenbergen of BNL, achieving about 1 MeV acceleration [A. van Steenbergen, J. Gallardo, J. Sandweiss, J.-M. Fang, M. Babzien, X. Qiu, J. Skaritka and X.J. Wang, "Observation of Energy Gain at the BNL Inverse Free-electron-Laser Accelerator", Phys. Rev. Let. 77, 2690 (1996)].

The same experimental setup also was used by another team led by Xijie Wang to measure the production of the world’s shortest electron bunches, about 1 micrometer long. [Y. Liu, X.J. Wang, D.B. Cline, M. Babzien, J.M. Fang, J. Gallardo, K. Kusche, I. Pogorelsky, J. Skaritka and A. van Steenbergen, "Experimental Observation of Femtosecond Electron Beam Micro-bunching by Inverse Free-Electron-Laser Acceleration, Phys. Rev. Lett. 80, 4418 (1998)].

Extremely short bunches are important for a variety of applications, from the generation of coherent radiation to injection into laser accelerators. Bunching by ballistic compression in the electron gun an experiment led by Xijie Wang, provided another record result [X.J. Wang, X. Qiu and I. Ben-Zvi, "Experimental Observation of High-Brightness Micro-Bunching in a Photocathode RF Gun", Phys. Rev. E54 No. 4, R3121, (1996)].

A number of important results were obtained in the area of Free-Electron Lasers (FEL). The first was the achievement of gain in Self Amplified Spontaneous Emission (SASE) in the visible and near IR. This result, led by Ilan Ben-Zvi, was shorter in wavelength by an order of magnitude from any previous result, demonstrating the very high brightness of the ATF beam. [M. Babzien, I. Ben-Zvi, P. Catravas, J-M. fang, T.C. Marshall, X.J. Wang, J.S. Wurtele, V. Yakimenko, L.H. Yu, "Observation of Self-Amplified Spontaneous Emission in the Near-Infrared and Visible Wavelength", Phys. Rev. E 57 6093 (1998)].

Another FEL ’first’ is the demonstration of High-Gain Harmonic-Generation FEL. This experiment is a proof-of-principle for a new generation of FELs that can provide highly coherent radiation in short wavelengths where mirrors cannot be used. The spokesperson of this experiment is Li Hua Yu. [L.-H. Yu, M. Babzien, I. Ben-Zvi, L.F. DiMauro, A. Doyuran, W. Graves, E. Johnson, S. Krinsky, R. Malone, I. Pogorelsky, J. Skaritka, G. Rakowsky, L. Solomon, X.J. Wang, M. Woodle, V. Yakimenko, S.G. Biedron, J.N. Galayda, E. Gluskin, J. Jagger, V. Sajaev, I. Vasserman, High-Gain Harmonic-Generation Free-Electron Laser, Science, **289** (2000) 932.]

The SASE-Free Electron Laser Experiment, VISA, at the ATF Linac. (Spokesperson: C. Pellegrini, UCLA, participants from BNL, LANL, LLNL and SLAC) is designed to test the most challenging aspects of X-ray FELs such as the LCLS in terms of undulator precision and strong focusing, beam quality and many other aspects. At the time of writing the FEL is delivering exceptionally high gain.

We return to the area of diagnostics by mentioning another ’first’ in diagnostics obtained at the ATF. This one, led by the (then) graduate Palmyra Catravas, is the use of undulator radiation as a non-invasive diagnostic of beam bunch length and emittance, [P. Catravas, W.P. Leemans, J.S. Wurtele, M.S. Zolotorev, M. Babzien, I. Ben-Zvi, Z. Segalov, X.J. Wang, V. Yakimenko, Measurement of Electron-Beam Bunch Length and Emittance Using Shot-Noise-Driven Fluctuations in Incoherent Radiation, Phys. Rev. Lett. 82 no. 26, 5261, (1999)].

The list of novel diagnostics does not end there. The precision tomographic measurement of the beam density in phase-space, the work of Vitaly Yakimenko, has been done in a number of ways at the ATF, including the demonstration of the effect of variations in the electron density [V. Yakimenko, M. Babzien, I. Be-Zvi, R. Malone, X.-J. Wang, Emittance Control of a Beam by Shaping the Transverse Charge Distribution, Using a Tomography diagnostic. Proceedings of EPAC’98, June 22-27, Stockholm, Sweden, page 1641], tomographic measurement of a single longitudinal slice and others.

An international experiment on beam instrumentation is the experimental test of a high precision, inexpensive beam position monitor for linear colliders, led by Vladimir Balakin of Protvino, Russia. The cavity-based beam-position monitor achieved so far a resolution of 150 nm in a single shot of less than 0.5 nC beam charge, and sub 100 nm resolution is anticipated. The initial result from the experiment was the subject of an invited talk at PAC’99, [V. Balakin, A. Bazhan, P. Lunev, N. Solyak, V. Vogel, P. Zhogolev, A. Lisitsyn, V. Yakimenko, Experimental Results From a Microwave Cavity Beam Position Monitor, Proc. of the 1999 Particle Accelerator Conference, A. Luccio, W. MacKay, Editors, 461, (1999)].

Another international experiment, this time Japanese-American collaboration, is the Thomson Scattering of a laser of the electron beam. The purpose of this experiment is to develop a technique to produce polarized positrons for linear colliders. As a by-product, this experiment is a unique source of picosecond x-rays in an unprecedented number of photons per pulse.

This partial list will be concluded by describing the STELLA (Staged Electron Laser Accelerator) results. This experiment is the first of the second-generation laser acceleration experiments. STELLA was designed to demonstrate that one can stage in series two laser accelerators, phase and match them as well as to demonstrate that the beam quality of laser accelerators can be good. These are essential steps on the way to practical future laser accelerators. The experiment succeeded in doing so. [W. D. Kimura, M. Babzien, I. Ben-Zvi, L. P. Campbell, D. B. Cline, J. C. Gallardo, S. C. Gottschalk, P. He, K. P. Kusche, Y. Liu, R. H. Pantell, I. V. Pogorelsky, D. C. Quimby, J. Skaritka, A. van Steenbergen, L.C. Steinhauer, and V. Yakimenko, ÒDemonstration of a Laser-Driven Prebuncher Staged With a Laser Accelerator - The STELLA Program,Ó to be published in the proceedings of the 9th Workshop on Advanced Accelerator Concepts, June 10-16, 2000, Santa Fe, NM.] The layout of the experiment is shown in Figure 7, together with three electron beam energy spectra: The spectrum with laser off, with first stage on and with both stages on. The first stage modulates the energy of the beam. Following bunching of the beam (to microbunches about 3 to 4 femtosecond long) the second stage accelerates the bunches with a good energy spread, about 1% to 2 %. The stability is the system is remarkable, although long-term drifts were observed in the phasing of the two laser accelerator sections.

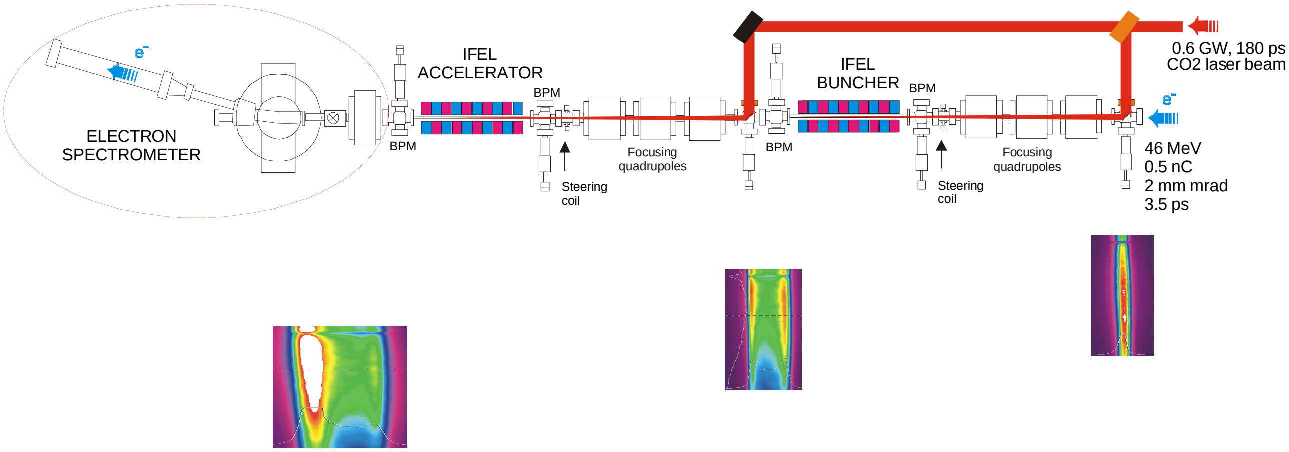

Figure 7. Drawing of the layout of the STELLA experiment on Beam Line 1 at the ATF. The electron energy spectra show the beam with both laser accelerators off (right), buncher on (middle) and both buncher and accelerator on (left).